THE LIMITS OF VARIATION IN PLANTS.

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One of the most important questions on which the work of the biologist should be brought to bear is the problem of species. We see all living nature—animals and plants—divided into groups which are denominated species. These groups are often clearly and sharply defined, and, on the other hand, often very irregularly characterized. What are the causes which have brought this about? What are the facts underlying the phenomenon of species? Two difficulties are presented to the earnest student who attempts to formulate an answer to the above-mentioned questions. The well-known reasoning starts from the fact that more animals or plants are born than can survive; some must therefore perish and leave no descendants, and only those persist which have structures and aptitudes that fit those organisms possessing them to bear their part in the struggle for existence. On the whole, we find that the fittest will survive and breed.

The first difficulty which presents itself is one which hangs on the magnitude of the variations by which new forms arise. What are the limits of variation? The older books on evolution consider that the variations by which new species arise are at first small. But if they are small, how can they be sufficiently useful to give to those organisms possessing them an advantage in the struggle for existence? This is the difficulty of small or initial variations.

The second difficulty is one known as that of the swamping effect of intercrossing. Granting that variations do occur, how can they be perpetuated? For if the varying individuals breed with each other, will not these variations be obliterated?

The following statistical study was undertaken with the purpose of answering the first question, viz.: By what steps—by what integral changes, of what size—did the new form come into existence? At the International Botanical Congress, held in Paris in 1900, M. Angel Gallardo spoke highly of the employment of the

statistical method in the study of variation,[1] and it appears to the writer that this method is the only accurate and scientific one that can be employed. Several plants, therefore, were chosen, because of their easy procurement, and measurements were made of their several parts and these measurements tabulated. Several striking facts were brought out during the course of the statistical inquiry, and these are referred to in their proper place throughout the paper.

The following common plants were chosen for a somewhat detailed measurement of the parts mentioned, viz.: Fruits of the May apple (*Podophyllum peltatum*), leaves of the tulip poplar (*Liriodendron tulipifera*), leaves of the Japanese ivy (*Ampelopsis Veitchii*), fruits of white oak (*Quercus alba*), fruits of the swamp chestnut oak (*Quercus prinus palustris*), leaves of the moon-seed (*Menispermum canadense*), entire plants of Indian turnip (*Arisœma triphyllum*), leaves of bloodroot (*Sanguinaria canadensis*), leaves of the tree of heaven (*Ailanthus glandulosa*)—the latter plant not being studied statistically, but in a comparative way to bring out some peculiarities of its pinnation. The material was used either in the green condition or it was used in the preserved state (dry or alcoholic). In all cases where leaves were taken, careful tracings were made by a sharp-pointed lead pencil upon ordinary drawing or manila paper, and these tracings were afterward accurately measured. The character of the material, whether fresh, dry or alcoholic, is mentioned in connection with the subjoined tables. Prof. Halsted[2] has shown that leaves suffer in drying, but in drying, as they all maintain the same relative size, the results which are mainly comparative do not seem to be vitiated.

The measurement of the linear dimensions of the leaves and parts of the plants was made by a standardized boxwood scale manufactured by Keuffel & Essler Co., New York, which ruler was divided into centimeters, millimeters and half-millimeters, the length of the scale being twenty centimeters in all. Superficial dimensions, in order to be accurate and expressive of the real size of the leaf or other part, require a detailed trigonometrical calcu-

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[1] 1900, *Botanical Gazette*, "Account of the International Botanical Congress," xxx, p. 405.

[2] Halsted, *Bulletin Torrey Botanical Club*, xxi, p. 127.

lation of areas by means of the angles and the sides of plane and spherical triangles, the sides of squares, rectangles, trapezoids and the like. Nothing being gained by such a mathematical study, measurements of the superficial extent of the vegetal parts are omitted. Linear dimensions in the tables are given in decimeters, centimeters and millimeters.

The weight of the fruit and seeds of the May apple are given in grams and decimals of the gram. The volume in cubic centimeters was determined by the amount of distilled water displaced by putting the fruits, the carefully cleaned and dried seeds, in a vessel filled to the brim with that liquid.

The linear measurements of the veins of the leaves used were obtained by adopting the following method of procedure. The midrib was first carefully measured, then the first line drawn on the left side from the base of the leaf to the apex of the first left lobe, and the second and third lines were also measured in the same manner.[3] The length of the parts on the right side was then determined, as also the depth in certain cases of the sinuses, beginning with the first sinus on the left of the middle lobe. Proceeding in the same way, after completing the measurements on the left, the right-hand side of the leaf was measured, the apex pointing away from one's person. The greatest width of the several lobes is also given in the tables, and the width of the widest portion of the leaf itself is also stated by way of a comparison.

MEASUREMENTS.

Podophyllum peltatum (Mayapple).

Twenty fruits were gathered in an open wood, carefully washed and wiped to remove adhering soil particles. After weighing, the volume of each fruit was determined, and afterward the seeds were removed, dried carefully, cleaned and weighed. The volume of the seeds was also ascertained by displacement. By subtracting the weight of the seeds from the weight of the fruit, the weight of the pulp may be ascertained, and in the same manner, by sub-

[3] Measurements of the fifth and sixth leaves of Table IV, part 1 were made from a base line drawn from lowest part of the two basal lobes. In the same manner also for leaves 1, 2, 3 of Table III, part 1, for D and E leaves Table V.

tracting volumes, its volume. The following table (I) presents the results of these determinations:

I. Fresh Fruits of Mayapple (Podophyllum peltatum).

Number.	Weight of Fruit, in Grams.	Volume of Fruit.	Number Seeds.	Weight of Seeds, in Grams.	Volume of Seeds.
1	30.05	34 c.c.	44	0.70	1.00 c.c.
2	35.50	36 "	52	0.90	.1.25 "
3	27.00	30 "	43	0.45	0.75 "
4	28.50	30 "	43	0.55	1.00 "
5	32.50	36 "	36	0.38	0.75 "
6	27.00	26 "	36	0.40	0.75 "
7	27.00	30 "	58	0.80	1.00 "
8	23.10	25 "	32	0.30	0.75 "
9	19.80	18 "	28	0.05	0.50 "
10	22.60	30 "	33	0.25	0.50 "
11	20.50	28 "	43	0.43	0.75 "
12	19.00	20 "	42	0.32	0.75 "
13	17.00	17 "	31	0.05	0.50 "
14	16.50	18 "	32	0.25	0.50 "
15	16.50	13 "	—	——	——
16	13.50	13 "	27	0.15	0.625 "
17	14.70	10 "	36	0.20	0.50 "
18	13.80	15 "	39	0.20	0.50 "
19	10.30	10 "	2	0.06	——
20	14.50	9 "	42	0.35	0.875 "

A study of this table shows that the size of the fruits and the number of the seeds varies within wide limits. The largest fruit with 52 seeds (No. 2) weighed 35.50 grams and displaced 36 c.c. of water. The smallest fruit (No. 19) with 2 seeds weighed 25.20 grams less, and displaced 10 c.c. of water, a difference of 26 c.c. This difference is due, without doubt, to imperfect fertilization of the ovules of the nineteenth plant. However, if we compare fruits No. 3 and No. 11, having the same number of good seeds, we find a very considerable difference; or if we institute a comparison between fruits No. 5 and No. 17, we find the variations to be even more striking. The table also shows that the weight of the fruit largely depends on the amount of the pulpy pericarp.

Sanguinaria canadensis (Bloodroot).

There arise from the rootstock of this plant two lanceolate, membranous scale leaves, and a single palmate, glaucous foliage leaf variously lobed, sometimes only undulate. A reference to the table will show that the thirty-three leaves taken for comparison

are extremely variable, the variations being within wide limits. The first leaf, an evolved one, was the largest one measured. If it is contrasted with a juvenile leaf No. 15, one of the smallest leaves, a wide divergence is noted. It is important, however, to notice here that an absolute comparison cannot be drawn, because of the wide variation in parts of the leaves themselves. For example, although in most of its dimensions leaf No. 15 is a small one, yet its midrib is longer than the midrib of No. 9, which is a middle-sized one. Therefore in comparing the large leaf No. 1 with the smallest leaf No. 15, these variables must be taken into consideration.

It is important to distinguish between the juvenile and adult forms of leaves. The differences in the construction of the juvenile and adult form are in general more different when the external conditions to which they are severally adapted are different; whilst if these do not operate, the primary leaves with which we have here first to deal are only arrested formations. In many plants reversion of the adult to the juvenile form frequently occurs. Evidently leaf No. 15 represents a juvenile form of leaf, that is, one derived from a rootstock which has been directly formed from the seedling plant, and the larger more deeply lobed leaves, such as No. 1, represent forms derived from a rhizome which has persisted for some years. In making these statistical measurements, therefore, the amount of the difference between the juvenile and adult forms is clearly set forth, as also the adult leaf variations mathematically expressed.

In the accompanying tables (II and II*a*), L. = length, W. = width of lobe, a star (*) beside a number indicates that the determination of the width of that lobe was made by measuring the length of a perpendicular from a line drawn from the base of a leaf to the apex of the lobe. The measurements were made from a basal point where the primary veins of the leaf meet. Fresh leaves were used in making the sketches from which the dimensions later were taken. The lowest point of the leaf was ascertained by measuring from the vein of the last and lowest lobe of the leaf on the right and left sides to the apex of the most projecting curve or angle toward the base of the leaf. The breadth of the leaf was determined by measuring across the widest portion of the leaf lamina.

II. Sanguinaria canadensis. Left Sides of Leaves.

Number of Leaf.	Mid-Lobe.		Depth Basal Sinus	1st Left Lobe		Depth of First Left Sinus.	2d Left Lobe		Depth of Second Left Sinus.	3d Left Lobe		Depth of Third Left Sinus.	Lowest Point Left Side.
	L.	W.		L.	W.		L.	W.		L.	W.		
1	.130	.025	.034	.170	.023	.065	.120	.040	.065	.120	.040	.069	.085
2	.053	.018	.024	.055	.021	.027	.050	.042	.020				.040
3	.112	.040	.050	.109	.038	.045	.100	.037	.037	.095	.039	.029	.074
4	.073	.025	.032	.070	.095	.022							.055
5	.063	.020	.037	.064	.027	.027	.051	.058					.044
6	.073	.028	.050	.071	.105	.026	.072						.060
7	.074	.029	.034	.062	.032	.026	.064	.064	.019				.047
8	.083	.026	.040	.081	.032	.030	.080	.077	.020	.078			.061
9	.046	.018	.047	.056		.017	.065	.087					.050
10	.055	.020	.050	.065		.017	.072	.105					.063
11	.063	.024	.040	.062	.095	.025	.056						.050
12	.070	.023	.037	.069	.027	.030	.064	.029	.021	.063	.046	.017	.050
13	.096	.043	.066	.100	.047	.047	.073	.096	.026				.069
14	.065	.022	.040	.067	.028	.025	.056	.028	.017	.058	.034	.016	.050
15	.050	.013	.030	.052	.072	.015	.046						.037
16	.057	.015	.033	.053	.082	.018	.053						.042
17	.104	.040	.050	.094	.047	.043	.093	.037	.034	.090	.059	.027	.064
18	.083	.028	.040	.071	.026	.038	.070	.077	.028				.056
19	.090	.029	.038	.082	.030	.039	.064	.030	.025	.063	.045	.021	.053
20	.070	.031	.064	.068	.035	.035	.070	.028	.028	.073	.044	.022	.068
21	.090	.037	.063	.085	.040	.045	.077	.045	.028	.076	.050	.021	.067
22	.092	.036	.052	.092	.036	.044	.079	.042	.023	.076	.043	.023	.063
23	.087	.030	.045	.088	.044	.043	.078	.035	.020	.080	.040*	.016	.060
24	.082	.026	.061	.075	.036	.045	.070	.086	.030				.070
25	.085	.032	.051	.088	.035	.040	.078	.036	.035	.074	.050	.022	.065
26	.070	.030	.033	.067	.032	.031	.063	.041*	.021				.050
27	.097	.032	.066	.090	.032	.051	.086	.034	.035	.080	.051	.025	.080
28	.066	.028	.034	.061	.025	.029	.056	.029	.023	.056	.023*	.015	.040
29	.097	.036	.051	.095	.043	.045	.091	.040	.034	.087	.038*	.026	.068
30	.088	.030	.054	.085	.036	.042	.083	.038	.031	.068	.060	.016	.062

IIa. Sanguinaria canadensis. Right Sides of Leaves.

Number of Leaf.	1st Right Lobe.		Depth of First Right Sinus.	2d Right Lobe.		Depth of Second Right Sinus.	3d Right Lobe.		Depth of Third Right Sinus.	Breadth of Leaf, Widest.	Lowest Point Right Side.
	L.	W.		L.	W.		L.	W.			
1	.120	.032	.068	.121	.042	.066	.122	.046	.057	.242	.098
2	.048		.025	.045	.057					.095	.032
3	.108	.037	.044	.098	.035	.030	.097	.055	.027	.177	.074
4	.072	.091	.022							.134	.051
5	.062	.024	.025	.062	.058					.110	.041
6	.069	.030	.024	.067	.070					.139	.058
7	.065	.035	.026	.064	.050	.020				.127	.048
8	.083	.029	.026	.076	.076	.019	.074			.151	.055
9	.053		.016	.064	.085					.120	.052
10	.058		.016	.061	.095					.115	.057
11	.064	.092	.023	.053						.113	.041
12	.065	.028	.030	.064	.062	.020	.063		.011	.125	.051
13	.090	.043	.050	.066	.100	.030				.136	.080
14	.064	.024	.024	.050	.031	.019	.054	.037	.013	.123	.042
15	.052	.071	.012	.045						.098	.040
16	.052	.078	.018	.050						.106	.042
17	.092	.042	.046	.085	.056	.035	.085	.056	.024	.172	.064
18	.070	.028	.026	.067	.071	.026				.130	.053
19	.085	.025	.035	.070	.033	.029	.066	.063	.023	.128	.055
20	.070	.033	.036	.067	.035	.033	.069	.049	.021	.130	.066
21	.088	.043	.044	.072	.033	.025	.072	.050	.020	.145	.069
22	.088	.043	.043	.080	.045	.028	.075	.047	.022	.158	.062
23	.080	.035	.043	.082	.036	.029	.081	.040*	.023	.160	.062
24	.078	.033	.042	.067	.080	.023				.137	.068
25	.086	.040	.046	.082	.032	.036	.072	.075	.024	.137	.060
26	.067	.030	.031	.062	.042*	.018				.123	.051
27	.089	.032	.048	.077	.035	.037	.076	.047	.019	.162	.076
28	.059	.024	.029	.055	.027	.026	.053	.030	.020	.108	.044
29	.092	.040	.042	.090	.037	.027	.086	.045*	.028	.170	.062
30	.092	.035	.040	.068	.030	.028	.068	.045	.030	.131	.060

Liriodendron tulipifera (Tulip Poplar).

The leaves of this tree are extremely variable, and different forms of leaves are found by careful examination on the same tree, as so clearly shown by Holm,[4] who has reduced many of the fossil species established by Heer, Lesquereux and Saporta to the *tulipifera* form, by finding that a large number of the fossil leaves upon which specific characters were founded are duplicated by the leaves from living trees. Goebel[5] has shown that it is necessary, in studying leaf forms, to contrast the juvenile and adult conditions, because these vary from each other within wide limits. It is of course impossible to limit these sharply. The difference between these juvenile stages and the adult form may be more or less great. The present statistical inquiry is intended to mathematicallv contrast these variations. The juvenile forms of leaves in *Liriodendron*, beginning with the first leaf above the cotyledons, may be described as follows: The first leaf is obreniform, *i.e*, two rounded lobes and rather deep angular sinus; the second leaf is approximately bilobed, somewhat squarer than a typical obcordate leaf; the third and fourth leaves are deltoid with shallow apical sinus, and therefore almost horizontal on top; the fifth leaf from the cotyledons is four-lobed with deep, rounded left and right sinuses, shallow apical sinus and two distinct obtuse apical lobes; the sixth leaf is entire, almost square, with two small lateral lobes and narrowed apical portion. In general, the first four or even five leaves on the very young tulip tree have the same form as the oldest and youngest on the branches of the full-grown tree. The best description of the adult leaf is by A. Michaux,[6] as follows: " Foliis abscisso-truncatis, quadri-lobatis," and this description has been accepted by such authorities as Bentham and Hooker, and Gray. Britton[7] describes the leaves in this manner: " Leaves glabrous, very broadly ovate or nearly orbicular in outline, truncate or broadly notched at the apex, truncate, rounded or cordate at the base, 3′–6′ long with 2 apical and 2–4 basal lobes with rounded sinuses, or occasionally entire." The juvenile leaves, as above described, vary remarkably from those adult forms described

[4] 1890, Holm, "Notes on the Leaves of Liriodendron," *Proceedings of the National Museum*, XIII, p. 15.

[5] Goebel, *Organographie der Pflanzen*, I. Theil, pp. 121–151.

[6] 1803, A. Michaux, *Flora Boreali-Americana*, p. 326.

[7] 1897, Britton and Brown, *Illustrated Flora*, II, p. 49.

so carefully by Britton and Michaux. In order to correlate the different varieties with one another, it is necessary to ask two questions: Is the leaf form an arrested one, or does it represent an advanced condition of growth? I believe that all the forms known can be classified either as arrested, evolved or reverted forms. Before, however, making this classification, it is necessary to state the fact that the oldest and youngest leaf on the same branch show an entirely different form from the intermediate ones, of which the form with four-lobed leaf may be taken as the normal one for our *Liriodendron tulipifera.*[8] The fact that the oldest and youngest leaf on the same branch can differ so much from the other ones seems to be almost constant for the full-grown tree. It must also be emphasized that the intermediate leaves have, instead of four lobes, sometimes six or even eight lobes as teeth.

Arrested Leaves.—The oldest and youngest leaves which have a shape somewhat like those of the seedling plant are evidently arrested ones. The primordium of the youngest leaf of a normal branch has been arrested in its development at a certain stage, and therefore the leaf exhibits an evident often extremely different configuration.

Reverted Leaves.—The gigantic leaves from the sprouts (measures below) evidently belong to this category, and are in shape like leaf No. 5 of the seedling tree.

Evolved Leaves.—The four-lobed leaves, whether provided with deep or shallow sinuses, and the six to eight-lobed leaves referred to above have acquired their different character by passing through a further transformation. In other cases where this rough classification does not apply, the form of the leaf may be explained by the persistence or duration of the juvenile form, which produces leaves scarcely less variable than the others mentioned above. All of these facts have been taken into consideration in making the measurements.

In Table III are presented the measurements of two terminal normal branches, the leaves being counted from the base in an ascending direction. The amount of variation is shown by comparing the leaves of the same position on the two shoots. The statistical study of the youngest, oldest and intermediate leaves of the normal branch brings out quantitatively the effect which the light exercises upon the development of the leaves. That light is

[8] Holm, *l. c.*

the controlling influence in regulating the size of dorsiventral organs, such as foliage leaves, has been abundantly proven. The measurements presented in Table III will at some future time be compared with those obtained from seedling plants, so as more clearly to present statistically the similarity of the youngest and oldest leaves of the normal shoot and the juvenile ones of the seedling tree.

Table IV presents the statistical study of the leaves of a normal shoot taken from a tree growing at Raven Rock, Pa. In comparing the figures of this table with those of Table III, it is necessary to read from the bottom up, leaf No. 7 of Table IV being compared with leaf No. 1 of Table III.

The leaves obtained from sprouts growing from a stump were out of all proportion to the size of the leaves on normally produced shoots. Table V shows the largest of the leaves studied to be .370 mm. long and .432 mm. wide. A comparison also of the leaves of the sprouts with each other indicates that a very considerable variation occurs. By contrasting these sprout leaves with normal ones, the limits of the variations in this one plant are clearly set forth. Variations which are due to the reversion of the sprout leaves to the juvenile forms on the seedling plants, however, enormously increased in size. It should be mentioned, also, that the stipules of the leaves on the sprouts are correspondingly increased in size, are permanent and assimilative, not caducous, as the small stipules of normal leaves. Measurements of these stipules are also given:

III. Fresh Leaves of Liriodendron tulipifera (two terminal shoots counting from base to apex).

No. of Leaf.	Midrib.	First L.Vein.	Second L.Vein.	Third L.Vein.	First R.Vein.	Second R.Vein.	Third R. Vein	Breadth Across Apex.	Breadth of Leaf.
1	.062	.083	.050		.081	.048		.078	.090
2	.090	.111	.068		.109	.065		.100	.116
3	.078	.099	.068		.101	.065		.090	.115
4	.084	.103	.067		.103	.068		.080	.111
5	.075	.092	.058		.089	.036		.067	.093
6	.081	.104	.056		.105	.060		.097	.113
Second Shoot.									
1	.080	.094	.075	.058	.098	.078	.062	.067	.136
2	.092	.108	.092	.072	.108	.088	.070	.071	.142
3	.094	.112	.092	.074	.115	.092	.073	.065	.140
4	.105	.121	.093		.138	.089		.073	.138
5	.087	.100	.079		.096	.075		.057	.105
6	.096	.108	.079		.112	.088		.068	.121
7	.082	.092	.073		.093	.073		.052	.098

IV. Normal Tree, Liriodendron tulipifera, Raven Rock, July 4, 1900 (open leaves counted from top).

	No. of Leaf.	Midrib.	First L. Vein.	Second L. Vein.	Third L. Vein.	First R. Vein.	Second R. Vein.	Third R. Vein.	Bre'dth Across Apex.	Bre'dth of Leaf.
Leaves from Terminal Shoot.	1	.135	.149	.120		.134	.141		.096	.164
	2	.165	.188	.147		.193	.153		.143	.221
	3	.156	.184	.142		.182	.131		.134	.226
	4	.147	.172	.126		.185	.146		.130	.213
	5	.156	.186	.157	.110	.179	.141	.102	.128	.236
	6	.133	.153	.105	.068	.156	.103	.069	.122	.182
	7	.080	.102	.083	.060	.093	.066	.044	.069	.132
Leaves from Lateral Sprout.	1	.068	.087	.075	.051	.088	.075	.051	.060	.115
	2	.076	.095	.076	.055	.090	.068	.046	.070	.127

V. Leaves of Liriodendron tulipifera Produced on Sprouts from the Stump (alcoholic material).

No. of Leaf.		Stipule.		Midrib.	First L. Vein.	Second L. Vein.	First R. Vein	Second R. Vein	Width Across Apex.	Width of Leaf.	Width of L'w'r Lobes.
		Length.	Breadth.	Length.	Length.	Length.	Length.	Length.			Meas. from Middle Vein.
Leaves on a Sprout Shoot	1	.031	.016	.035*	.039*	.028*					
	2	.028	.017	.097	.110		.114	.088	.052		.022
	3	.027	.018	.082	.108		.110		.085	.115	
	4	.040	.027	.370	.308	.213	.312	.253	.187	.432	.083
	5	.033	.034	.180	.198	.142	.212	.170	.121	.381	.056
Single Le'ves from Sprout.	A	.063	.044	.320	.362	.275	.355	.275	.203	.430	.108
	B			.276	.310	.227	.311	.245	.210	.432	.090
	C			.300	.337	.270	.338	.225	.218	.455	.100
	D			.343	.380	.300	.370	.282	.225	.435	.070
	E			.322	.342	.238	.364	.275	.206	.430	.074

* Unopened leaves.

Menispermum canadense (Moonseed).

The leaves of two entire plants of this species were taken, the leaves being numbered from the apex toward the base. In the first place, the table shows the limits of variability in the adult leaves of the same stem, and also contrasts the individual leaves of the two plants, leaf 5 or 6 of one plant being compared with leaf 5 or 6 of the other plant:

VI. Menispermum canadense (two plants in fresh state).

	No. of Leaf.	Mid-vein. Length.	First L.Vein. Length.	Second L.Vein. Length.	Third L.Vein. Length.	First R. Vein	Second R. Vein	Third R. Vein	Width of Leaf.	Petiole Attach-ment to Lower Edge.
	1	.012	.011			.010			.012	
	2	.021	.015			.014			.018	
	3	.020	.016	.009		.016	.010		.024	.004
	4	.029	.021	.013		.021	.013		.033	.003
I.	5	.040	.032	.019		.030	.019		.050	.005
	6	.052	.044	.029		.040	.026		.058	.004
	7	.062	.054	.039		.051	.032		.071	.008
	8	.079	.071	.056	.041	.073	.058	.044	.100	.009
	9	.043	.044	.034	.028	.041	.035	.026	.065	.004
	1	.008	.008			.008			.012	.030
	2	.018	.015			.014			.022	.002
	3	.033	.028	.020		.026	.018		.038	.005
	4	.053	.047	.037		.041	.032		.065	.008
II.	5	.067	.059	.050		.054	.045		.084	.007
	6	.067	.055	.047		.054	.047		.082	.007
	7	.060	.056	.051	.036	.054	.038	.038	.071	.008
	8	.057	.056	.036	.034	.048	.040	.032	.058	.005
	9	.049	.045	.034	.029	.045	.036	.028	.062	.003

Quercus alba (White Oak).

The size of the nuts enclosed by the cupule in the oak varies in an interesting manner. The fruits of two species of oak collected by Dr. J. T. Rothrock on October 19, 1863, were studied statistically. It is supposed that the fruits in drying preserved the same relative size that they had when in the fresh, fully ripe condition. The three swamp chestnut oaks from which the fruits were obtained were standing close together, and each was fully three feet in diameter. Table VIII presents the measurements of the swamp chestnut oak acorns, and Table VII those of the white oak:

VII. Quercus alba.

Large Fruits (Dry), Oct. 20, 1863.		
No. of Acorn.	Length.	Breadth.
1	.026	.018
2	.025	.016
3	.023	.016
4	.021	.015
Small or Ordinary Fruits.		
1	.020	.014
2	.019	.014
3	.017	.013
4	.018	.013
5	.018	.013
6	.020	.014

VIII. Quercus prinus var. palustris.

Small Fruited (Dry) October 19, 1863.		
No. of Acorn.	Length.	Breadth.
1	.015	.013
2	.016	.013
3	.015	.014
4	.015	.014
5	.015	.013
6	.016	.014
7	.016	.014
Middle Sized Fruit.		
1	.021	.017
2	.020	.017
3	.018	.016
4	.018	.016
5	.017	.015
6	.017	.016
7	.017	.015
Large Fruits.		
1	.023	.019
2	.022	.021
3	.022	.020
4	.022	.020
5	.019	.018

Arisæma triphyllum (Indian Turnip).

Two plants were collected in the woods at Shawmont, Pa., growing under exactly similar conditions of soil and light exposure. The following measurements present in a statistical manner the variations which occur in the leaves and other parts of the two plants. The number of perfect fruits depended upon the success of the process of fertilization. The number of seeds in each berry varies from 1 to 4 in number:

IX. Arisæma triphyllum (two plants).

Number of Plant.	Corm.		Scape.	Petiole.	Leaf Sheath.	Fruits.	
	Width.	Height.	Length.	Length.	Length.	Perfect.	Abortive.
First Plant....	.030	.033	.335	.630	.260	55	10
2d Plant — A Leaf			.430	.665		86	
2d Plant — B Leaf				.645			

X. Arisæma triphyllum (leaves of two plants).

Number of Plant.	Mid-Leaflets.		1st Left Leaflet.		2d Left Lobe or Leaflet.		1st Right Lobe or Leaflet.		2d Right Lobe or Leaflet.	
	Length.	Breadth.	Length.	Breadth.	Length.	Breadth.	Length.	Breadth.	Length.	Breadth.
First Plant.........	.194	.155	.215	.145	.075 lobe	.030 lobe	.225	.146	.155	.094
Second Plant — A Leaf....	.178	.159	.220	.147	.152	.083	.218	.150	.157	.083
Second Plant — B Leaf....	.195	.127	.180	.123			.180	.116	.078	

Ampelopsis Veitchii (Japanese Ivy).

The measurements of the leaves of this plant are presented in Table X. The young plants have normally trifoliate leaves and unifoliate ones interspersed. The seedlings always have trifoliate leaves without any unifoliate ones. This points to the ancestor of

both the Japanese species (*Ampelopsis Veitchii*) and the American species (*A. quinquefolia*) as one with three leaflets, the Japanese species later becoming unifoliate, the American species developing five leaflets, the seedlings of both plants being trifoliate.

X. Ampelopsis Veitchii. Measurements of Leaves (Fresh).

		Trilobed or Trifoliate Leaves.								Unifoliate Leaves.					
		Mid 1st Leaflet.		L. 2d Leaflet.		R. 3d Leaflet.		1st Sinus Depth.	2d Sinus Depth.						
	Number.	Length.	Breadth.	Length.	Breadth.	Length.	Breadth.	Left Side.	Right Side.	Midrib Length.	1st Left Vein.	2d Left Vein	1st Right Vein.	2d Right Vein.	Breadth.
1st Lateral Spur.	1	.037	.018	.032	.022	.026	.014								
	2	.023	.015	.025	.016	.024	.018	.023	.014						
	3	.023	.015	.017		.020	.013		.016						
	4	.016	.011	.020	.012	.015	.010								
2d Lateral Spur	1									.021	.017		.017		.026
	2	.035	.015	.026	.014										
	3	.034	.019	.028	.016										
3d Lateral Spur.	1									.023	.015		.016		.025
	2	.038	.021	.032	.018	.030	.018								
	3	.028	.015	.025	.014	.031	.019								
	4	.037	.027	.032	.022	.033	.020								
4th Lateral Spur	1									.040	.036	.018	.038	.020	.043
	2	.025	.017	.019	.015	.015	.011	.009	.008						
	3	.050	.030	.043	.015	.039	.020								

Ailanthus glandulosa (Tree of Heaven).

Some interesting facts were brought out in the study of the leaves of this species. Two kinds of leaves were met with, viz., transformed or evolved leaves and arrested ones. In order properly to understand the variations which have taken place, it is necessary to refer to the seedling condition as a starting-point. According to Lubbock,[9] the first leaves are compound, trifoliate, petiolate, exstipulate; terminal leaflets acuminate, subacute, entire; lateral ones slightly toothed, ultimately glabrescent, petiolate, light green, alternately pinnate-nerved; petioles ribbed or striated, covered with short glandular hairs; the young leaves are also covered with fine silky hairs near their edges. The normal fully developed leaves are pinnate with an odd leaflet provided, as a rule, with from 5 to 9 pairs of lateral leaflets. The youngest leaves of the side or terminal branches are juvenile in form and of two kinds, viz., undeveloped or arrested juveniles and seedling juveniles. For example, on one branch the lowest leaf is broadly lanceolate with two small lobes with glandular apices on the upper entire margin; the lower side has a larger glandular tipped lobe and an acute sinus. This leaf is an arrested juvenile one, the primordium growing out into the terminal leaflet before the formation of the paired lateral ones. The second leaf of the same branch is pinnately trifoliate; the lateral paired leaflets asymmetric, cut away obliquely on the lower margin and rounded on the upper, while the terminal leaflet is broadly ovate, acuminate with a single basal, glandular-tipped lobe on the upper margin. The other leaves of this branch are pinnate with an odd leaflet provided with 5 to 6 pairs of lateral leaflets. The odd leaflet is lanceolate with two glandular teeth on the lower margin and one on the upper.

The second branch studied shows a somewhat similar condition of affairs; the earliest formed leaf is more deeply lobed at the base, each lobe with rather deep sinuses, the upper narrow sinus cutting in almost to the midrib. The terminal leaflets of the pinnate leaves are also narrowly lanceolate with glandular teeth at the base. One leaf, however, is abruptly pinnate by the non-development of the terminal odd leaflet.

Two divergent types of leaves may be said thus to exist on the same tree, one type of leaf being due to the arrestment of the

[9] 1892, Lubbock, *Seedlings*, I, p. 327.

terminal odd leaflet. Several steps in this suppression of the odd leaflet were gathered. One pinnate foliage leaf shows a very narrow somewhat unequally trilobed odd leaflet; another a still narrower almost linear, glandular-toothed terminal leaflet. A third one has a filiform odd leaflet; a fourth pinnate foliage leaf has a simple boss in place of the odd leaflet, this small protuberance seeming to persist as a rudiment in all of the leaves studied. This arrestment of the normal development is carried a step farther, the terminal paired lateral leaflets beginning to manifest a reduction in size, becoming in one leaf studied small, elliptical in outline with a retuse apex, all the other leaflets studied having an acuminate apex. The other line of variation starts with the lanceolate odd leaflet which becomes increasingly broader. Some have a rounded, retuse apex, others have an acuminate point. From simple glandular teeth at the base of the odd leaflet, these glandular teeth increase in size until they become glandular tipped lobes separated from each other by rather shallow, acute sinuses, this line of advanced development proceeding until the terminal leaflet reaches a broadly ovate, trilobed form, each lobe being narrowly acuminate. Finally, as if to approach a climax, one of these lobes becomes almost distinct at the base, but is still concrescent with the basal part of the leaflet and the upper side of its petiole. In another leaf gathered, as representing the climax, this lanceolate entire basal lobe is separated by the cutting in of the sinus to the midrib; the asymmetric upper portion also becomes deeply lobed by the formation of rounded depressions. The lateral intermediate leaflets of the pinnate leaves are all asymmetric with an oblique base, the obliquity inclining downward. A glandular tooth is usually found on the upper and lower margins; if three glands are present, two are found on the lower margin, one on the upper. If only one gland is present it is always on the rounded, oblique lower edge. Occasionally a basal, rounded, glandular-tipped lobe is found on the lower edge of the lateral pinnæ of a large foliage leaf. We cannot doubt that asymmetry of leaflets chiefly appears when their parts are unsymmetrically related to their environment.[10] We may say in general, with Herbert Spencer, that that side of the leaf is the smaller which is shaded, and

[10] Herbert Spencer, *Principles of Biology*, II, p. 143.

that the obliquity of the leaf is occasioned by its fitting itself to utilize the space at its disposal.

Summary and Conclusion.

1. This study of the limits of variations in plants was undertaken as, in part, a contribution to the problem of species.

2. Moreover, this study was undertaken to provide statistical data which would throw light upon the difficulty, from an evolutionary standpoint, of small or initial variations.

3. Considerable variation in the size and shape of leaves is evident, and the amount of the variation was determined statistically; the weight and volume of fruits were calculated ; the number of seeds was determined.

4. The quantitative amount of variation in the juvenile, arrested and transformed leaves of a number of plants was also determined and tabulated.

5. In *Liriodendron tulipifera, Sanguinaria canadensis,* and *Ailanthus glandulosa* it was ascertained that variation in the size and configuration of the leaves of these plants is in part due to the persistence of juvenile forms, to the arrested development of such leaves, to their evolution and transformation to higher forms. The amount of these differences was also tabulated.

6. In conclusion, it may be stated that these changes in most cases are due to two causes: the internal hereditary impulse determining, as in *Ailanthus glandulosa,* the asymmetry of the lateral paired leaflets, and the direct environmental influence fitting the leaf to utilize the space at its disposal, and thus enabling it to present the largest amount of leaf surface to light action. We have, therefore, in the tables an exact mathematical expression of the influence of the various operating factors which determine plant form.